

INTENSITY AND COHERENCE CONTOURS DURING SELF-REGULATED HIGH ALPHA ACTIVITY

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Spectral intensity and coherence analysis of EEG activity during rest and during a period of self-regulated high alpha in two subjects indicate that:
1) Slow frontal activity, which is due primarily to eye movements, is less intense during successful alpha regulation than during baselines. 2) There is little evidence for increased intensity in frequency ranges other than the alpha range during alpha regulation. 3) Occipital alpha tends to be more coherent with frontal than with temporal alpha during occipital alpha regulation.

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CLINICAL NOTE

INTENSITY AND COHERENCE CONTOURS DURING SELF-REGULATED HIGH ALPHA ACTIVITY¹

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It is now generally accepted that subjects can learn to increase their alpha activity above resting spontaneous levels by means of self-regulation. Usually the increase of alpha is attributed to operant conditioning, in which the appearance of an alpha-contingent auditory or visual signal is fed back to the subject and acts as a positive reinforcer (Nowlis and Kamiya 1970; Brown 1970). The extent of this increase is typically measured by a filter, rectifier and relay device that provides an index of percent alpha during the period of alpha regulation.

The total EEG spectrum during the period of alpha enhancement has not been reported, nor has a measure of coherence between different regions of the scalp been used as a descriptive measure of the self-regulated high alpha state.

This report is based on EEG data obtained from two "practiced" alpha regulators and demonstrates the feasibility of using spectral intensity and coherence of frontal, temporal and occipital EEG as descriptive measures of the phenomena during a 1 h alpha regulation period.

METHOD AND MATERIAL

Two volunteer subjects, one male (AJ) and one female (EM), both in their twenties, participated in an alpha regulation study over 3 separate days. Both had previously experienced alpha training and had demonstrated an ability to increase or decrease their percent alpha on demand, using a contingent digital auditory feedback signal as a guide (Hord and Barber 1971). During each session, subjects sat upright on a hospital bed in a sound-attenuated, dimly illuminated room.

EEG activity from F_{p2}, T₄ and O₂ referenced to linked mastoids (A₁ and A₂) were recorded on 3 channels of a Beckman Type R Dynograph, and concurrently on 3 channels of a Hewlett Packard 3907C tape system. Amplified EEG from the O₂ lead was filtered at 10 c/sec by a Krohn-Hite 330BR variable bandpass filter. The output of the filter controlled an "alpha relay" constructed according to the specifications suggested by Pasquali (1969). The latter is essentially

a leaky integrator and was used in the present study as an alpha feedback device. Approximately 3 to 4 alpha waves were necessary to close the relay, and the relay stayed on approximately 0.5 sec after the end of an alpha burst. Because of the irregular nature of alpha burst length and inter-burst interval, a careful calibration of the voltage necessary to open and close the relay was not attempted. Relay closure was indicated on one channel of the polygraph. Relay closure time was simultaneously indicated on a Hewlett Packard 5321B Electronic Counter and was tabulated at 1 min intervals on the polygraph.

A BRS-Foringer audio generator and two speakers located approximately 4 ft on either side of the subject's head provided the feedback signal. Pitch and loudness of the tone were adjusted for each subject to a level that was not aversive, yet clearly discernible.

Each experimental session was divided into: (A) calibration epoch; (B) baseline epoch (10 min); (C) alpha regulation epoch (60 min); and (D) recovery epoch (10 min). Feedback to the subject was provided only during the alpha-regulation epoch. During the calibration epoch, subjects were instructed to close and open their eyes during successive 15 sec periods during which the threshold of the alpha relay was adjusted so that eyes closed turned the relay on and eyes open turned the relay off. Once this level was determined, it was not changed for the remainder of the session. The baseline epoch was then recorded, the subject having been told to relax and keep his eyes open. Following the baseline epoch, the subject was instructed to continue to keep his eyes open, and he was then informed that the tone would be heard only when his alpha was at a level comparable to what it had been during the eyes-closed condition of the calibration epoch. He was encouraged to keep the tone on as much as possible. Upon completing the alpha regulation epoch, the tone was disconnected and the subject was instructed to assume a state as near as possible to the previous baseline epoch for 10 min.

Magnetic tapes containing EEG, time code and calibration signal at 10 c/sec with 100 μ V double amplitude were digitized at 125 samples/sec. Spectral analysis was then performed on the data obtained from Day 3 of the experiment. One min polygraph samples of EEG from the 3 scalp leads were selected from the baseline epoch (B), the first 5 min period of alpha regulation (E₁), the fifth 5 min period of alpha regulation (E₅), the ninth 5 min period of alpha regulation (E₉), and the recovery epoch (R). The criterion for selection of data for

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computer analysis was freedom from extensive movement artifact. Corresponding samples of EEG were retrieved from the digital tapes for spectral intensity and coherence analysis. A version of the Fast Fourier Transform (FFT, see Jenkins and Watts 1968) was applied to the 8,192 data points per EEG sample. The FFT output was smoothed by applying equal averaging weights to non-overlapping groups of 32 sine and cosine coefficients, resulting in a frequency resolution interval of 0.49 c/sec.

Spectral intensity and coherence were then transcribed manually on contour maps using a method of linear interpolation (Naitoh and Walter 1969).

RESULTS AND DISCUSSION

In Fig. 1 are the maps of spectral intensity ($\mu\text{V}^2/\text{c/sec}$) as a function of the frequency-time plane. Intensity should be visualized as a third dimension extending up from the surface of the page. Various intensity cuts were made to show the general shape of the 3-dimensional display. Contour maps of coherence were generated in a manner similar to that for intensity and are shown in Fig. 2. The coherence of X and Y at frequency f is defined as

$$|\text{Cross-spectrum of } X \text{ and } Y \text{ at } f|^2$$

$$(\text{Auto-spectrum of } X \text{ at } f)(\text{Auto-spectrum of } Y \text{ at } f)$$

and is analogous to the ordinary squared correlation coefficient (Walter 1963; Jenkins and Watts 1968). Values of coherence are represented on the map as a third dimension extending up from the surface of the page. In the present study, cuts were made at 0.20, 0.40, 0.50 and 0.60 to give the general

shape of the 3-dimensional display. A more detailed analysis of the maps was made by slicing through at the frequency that corresponded to the highest occipital alpha activity, which was found to be 10.25 c/sec for both subjects. The results are shown in Table I.

Spectral intensity. In general, most of the spectral intensity at the F_{p2} and T_4 leads appeared in the frequency range 0.5–5.4 c/sec, with by far the greatest intensity in the low frequencies (0.5–2 c/sec). Most of the low frequency intensity observed during the baseline and recovery epochs could be attributed to eye movements. It seems to be the case that eye movements are prevalent before and after the alpha regulation epoch and are least likely to occur during successful alpha regulation. Despite a large difference in eyes-open alpha between the two subjects (see Table I), lead O_2 showed increasing intensity in the alpha range during alpha regulation in both subjects, reaching a maximum during E_o. There is some evidence for increasing intensity in the alpha range at the T_4 and F_{p2} leads, although the absolute increase is considerably less than at the O_2 lead. The data indicate that alpha regulation can occur near the frequency that is being reinforced (10 c/sec in this case), without noticeably affecting other frequencies. It may also be the case that alpha regulation is limited topographically to the region that provides the feedback signal, although such conclusions would have to be based on data other than that of the present study.

Coherence. Relatively high coherence (Fig. 2) was observed in the F_{p2} – T_4 combination in the same low frequency range where high intensity was found. Since most of this activity was due to eye movements, it was not surprising that coherence between these two locations was high. In the alpha range, the

TABLE I

Slices of the contour maps at 10.25 c/sec to show auto-spectral intensity and coherence of eye open alpha activity before (B), during (E) and after (R) self-regulation.

Subject code	EM			AJ		
	F_{p2}	T_4	O_2	F_{p2}	T_4	O_2
EEG leads*						
Auto-spectral intensity ($\mu\text{V}^2/\text{c/sec}$)						
B	32	10	81	5	7	7
E ₁	63	22	147	8	6	28
E ₅	36	10	120	9	11	10
E _o	44	16	170	55	42	414
R	31	8	74	13	6	8
Subject code	EM			AJ		
EEG leads	F_{p2} – T_4	T_4 – O_2	F_{p2} – O_2	F_{p2} – T_4	T_4 – O_2	F_{p2} – O_2
Coherence						
B	0.30	0.13	0.62	0.07	0.35	0.01
E ₁	0.58	0.30	0.75	0.29	0.01	0.29
E ₅	0.35	0.16	0.75	0.28	0.21	0.06
E _o	0.55	0.28	0.68	0.51	0.44	0.66
R	0.33	0.10	0.50	0.13	0.25	0.03

* Referenced to linked mastoids. See text for the details of B, E's and R.

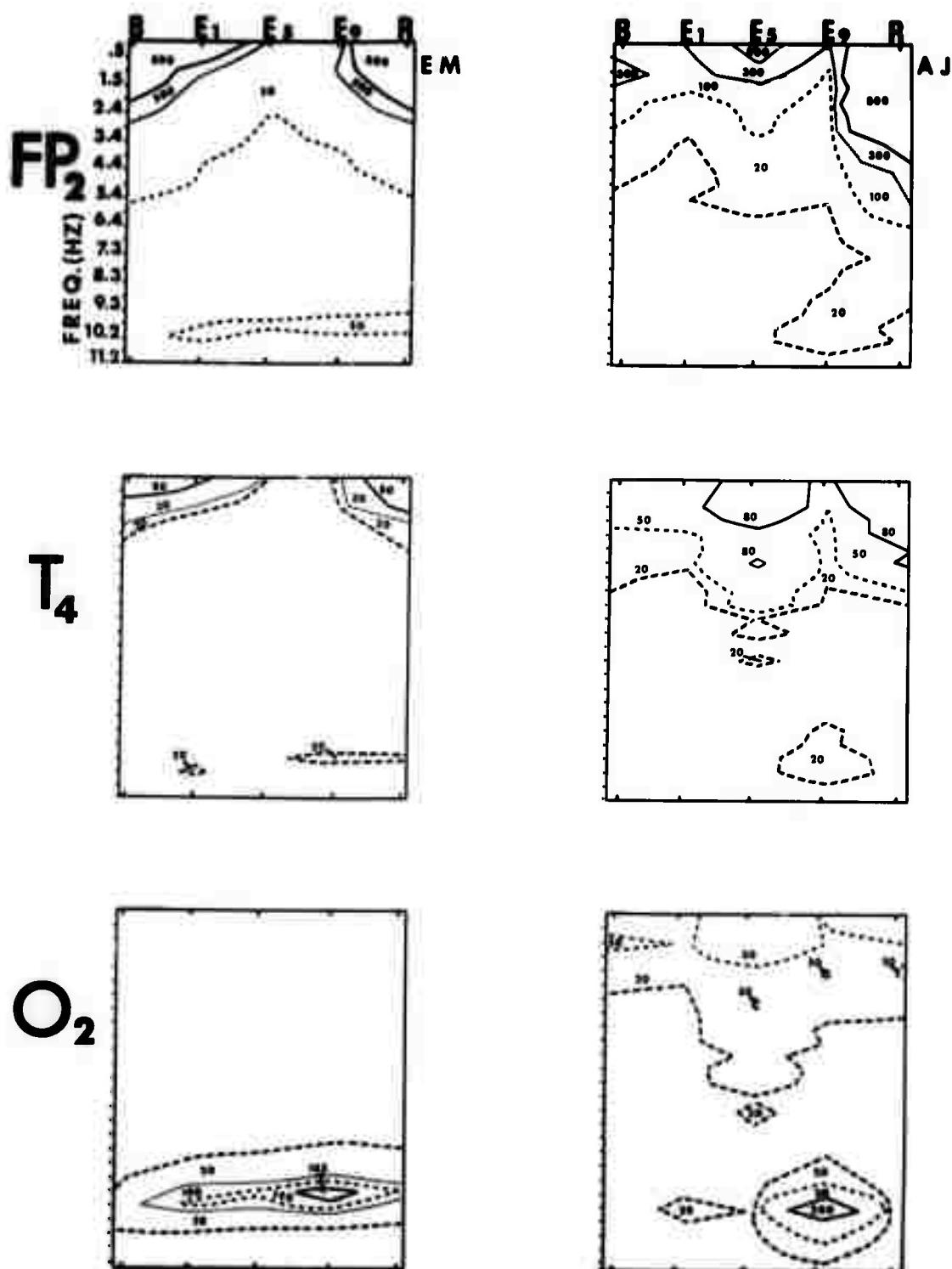


Fig. 1. Spectral intensity maps for two subjects, EM and AJ. Intensity is in units of microvolts²/c/sec and is contoured on the frequency-time plane. Numbers or "maps" refer to intensity "slices". Other symbols are defined in the text.

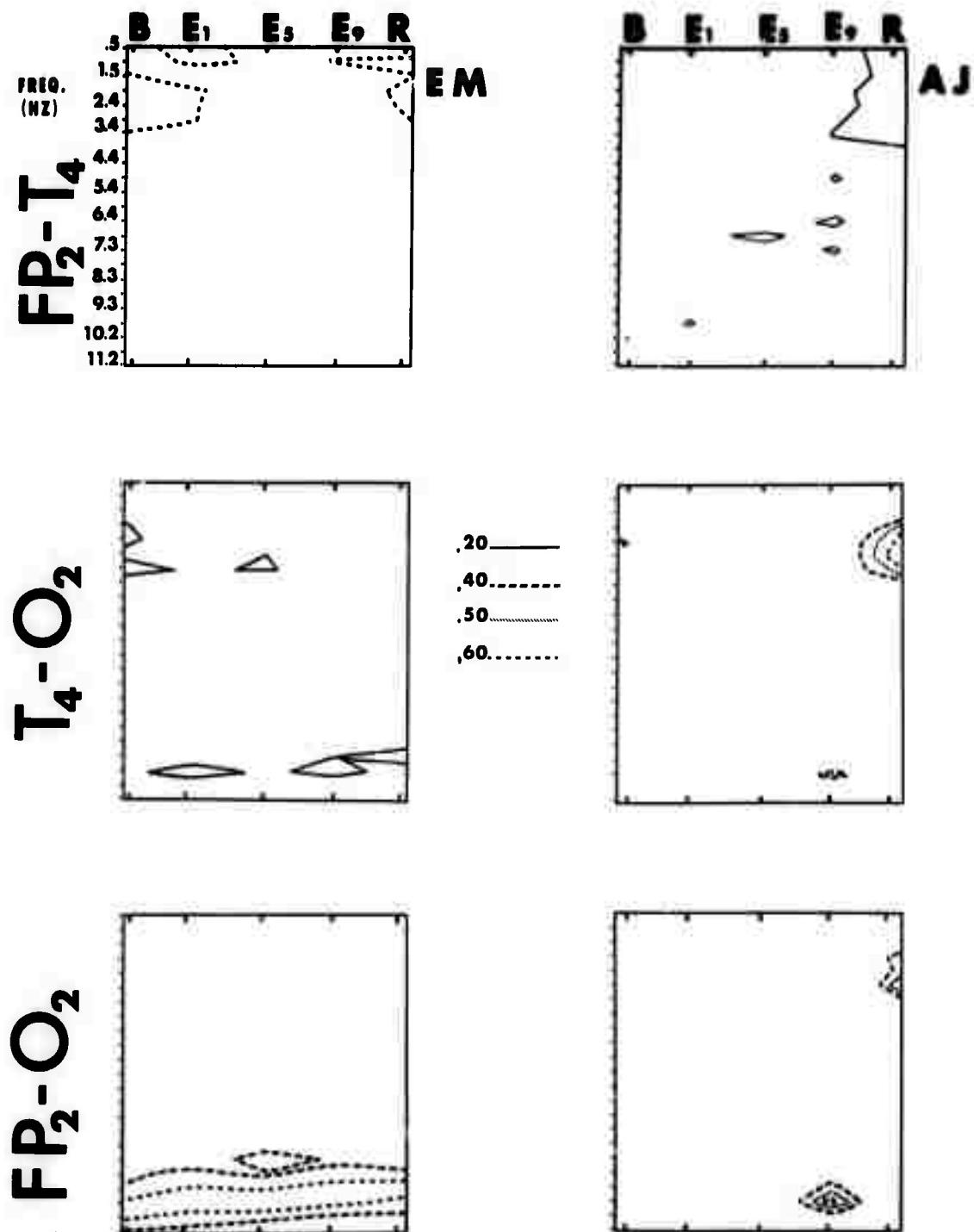


Fig. 2. Coherence contours for two subjects, EM and AJ. Four magnitudes of coherence are identified by the four different lines. Other symbols are defined in the text.

SPECTRAL ASPECTS OF SELF-REGULATED ALPHA

greatest coherence was in the lead combination F_{p2}, O₂ during the alpha regulation epoch. Some coherent alpha appeared in lead combinations that included T₄, but to a much lesser extent. One interpretation of this is that alpha generated and enhanced by self-regulation near O₂ has a greater tendency to appear in the frontal than in the temporal region of the scalp, even though the latter is spatially closer.

The two subjects showed quite different coherence values under the eye-open baseline condition. At 10.25 c sec, subject EM had a coherence of 0.62 between F_{p2} and O₂, whereas AJ had a near zero coherence in the same lead combination (Table I). Despite this individual difference in baseline coherence, both subjects achieved high coherence during the alpha-regulation epoch. During the recovery epoch, these high coherences attenuate to levels that are comparable to the baseline epoch.

Phase angles associated with these frequencies in those instances where coherence was above 0.40 had a mean value of -164 degrees, standard deviation of 6.48 on one day, and a mean value of -167, standard deviation of 6.32 on another day. These values correspond to a phase lag in which O₂ leads F_{p2} by approximately 45 msec. Using a similar type of analysis, Walter et al. (1966) reported 30 degree phase lag (equivalent to 15 msec) for coherent alpha waves that move forward from an occipital-parietal location to a parietal-central location during resting.

Although there is little evidence of change in frequency or spatial features of self-regulated alpha for the particular leads used in this study, the technique of using contingent reinforcers to manipulate these features may be of value in the study of alpha wave generators. For example, a measure of coherence between pairs of electrodes could lead to inferences about the existence of single, as opposed to multiple, generators. If a contingent reinforcer is applied to lead A of pair AB, and if coherence between A and B increases during the time of self-regulation, one might infer that a single generator was involved. On the other hand, if intensity at lead A can be increased, concomitantly with decreasing coherence with lead B, then the existence of multiple generators might be inferred.

SUMMARY

Spectral intensity and coherence analysis of EEG activity during rest and during a period of self-regulated high alpha in two subjects indicate that: (1) Slow frontal activity, which is due primarily to eye movements, is less intense during successful alpha regulation than during baselines. (2) There is little evidence for increased intensity in frequency ranges other than the alpha range during alpha regulation. (3) Occipital alpha tends to be more coherent with frontal than with temporal alpha during occipital alpha regulation.

RESUME

CONTOURS D'INTENSITE ET DE COHERENCE AU COURS D'UNE ACTIVITE ALPHA ELEVEE ET AUTO-REGULEE

Chez deux sujets, l'analyse d'intensité spectrale et de cohérence de l'activité EEG au repos et pendant une période d'activité alpha élevée auto-régulée indique que: (1) l'activité lente frontale, qui est due essentiellement à des mouvements oculaires, est moins intense lors d'une régulation alpha réussie qu'en condition standard. (2) Il y a peu de signes d'une augmentation d'intensité dans les bandes de fréquence autres que la bande alpha au cours de la régulation alpha. (3) Au cours de la régulation alpha occipitale, la cohérence de l'alpha occipital avec l'alpha frontal est meilleure qu'avec l'alpha temporaire.

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